

The Effects of Experimental Conditions on Coagulation Mixing

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Abstract—Coagulation mixing is an important process in water treatment, the selection of mixing parameters and operation conditions will affect the efficiency of water treatment directly. The optimal dosage of flocculant (PAC) was determined by the single-factor experiment, and the dosage is 1500mg/L. Through the orthogonal experiments, the optimum condition of coagulation mixing were found; And the effects degree of experimental conditions on coagulation mixing were found: fast mixing time > fast mixing speed > slow mixing time > slow mixing speed. This study provides theoretical support for the application of coagulation mixing in water treatment..

Index Terms—coagulation mixing, water treatment, flocculant, experimental condition

I. INTRODUCTION

Coagulation mixing is an important process in water treatment, the selection of mixing parameters and operation conditions will affect the efficiency of water treatment directly. The experiment of coagulation mixing [1], which began in 1921, is one of the most widely used methods in the study and control of coagulation process. There are many factors that affect the mixing experiment, such as the mixing speed and time, the shape of the mixing vessel, the size and shape of the mixing paddle and so on [2]. In this paper, through a series of experiments, the influence of experimental conditions on the coagulation mixing was researched, and some theoretical guidance for engineering practice was provided.

II. COAGULATION DYNAMIC THEORY

A. Coagulation mechanism

The condition of the particles which can get flocculated is the agglomeration of rough particles in water disperse system. The particles dispersed in water have certain thermodynamic stability and dynamic stability due to their unique surface properties [3]. The surface potential of particles is increased by the exchange or reaction between the surface molecules of the particles and the molecules in water or water molecules, and that increase impedes the combination of particles, the surface molecules of some particles can also be combined with water molecules to form a hydration film, which can also achieve the goal of impeding the combination of particles [4]. In the coagulation process, a small amount of chemicals was used to reduce the surface potential of the particle or destruct the hydration film and destruct the dynamic stability of particles, under the action of the Brown movement or the subsequent hydraulic conditions, the particles combined and become large sediments which can be removed from the precipitation and filtration unit [5].

B. Mixing mechanism

Mixing process is that through the diffusion of the main diffusion, the vortex diffusion and the molecular diffusion, the molecular level uniform mixing is reached under the condition of the forced convection [6].

In a mixing experiment, the rotating blades transfer the energy to the water by mechanical energy at first, and makes the water produce forced convection, then the high-speed rotation of the water flow is formed [7], which drives the circulation of all the internal water, this circulating flow which causes a wide range of water diffusion is called the main diffusion; While the blades are rotating fast in the water, there will be an instantaneous velocity gradient behind those blades and local shear flow, in this way, the larger scale vortex micro clusters in the water will be divided into scales of different size by turbulence shear force, meanwhile, the energy is also transferred from larger scale vortex to smaller scales until the vortex scale reaches the minimum which is the Kolmogoroff scale [8], this convection diffusion formed by the diffusion of different vortex scales in a local range is called the vortex diffusion [9]. The mixing effect can only be achieved by molecular diffusion when the vortex scale reaches Kolmogoroff scale.

III. COAGULATION MIXING EXPERIMENT

A. Experimental instruments and water samples

Experimental instruments: MY3000-6M Coagulation experiment six joint stirring device(Wuhan Mei Yu Co., Ltd.Fig.1), SGZ-1A Digital display turbidity meter(Shanghai Yue Feng Instrument Co., Ltd.) etc.



Fig.1 MY3000-6M Coagulation experiment six joint stirring device

Experimental water: the water sample is the oil well produced water which was simply treated by oil separation treatment of Jidong Oilfield in China. The turbidity of the water sample was 46.5, pH was 6.9, the experimental temperature was 20 DEG C. The flocculant was 10%PAC solution (Fig.2).



Fig.2 10% PAC solution

B. Experimental method

Use the single-factor experimental method to determine the appropriate flocculant dosage, the dosage is divided into 5 levels, respectively as 200mg/L, 500mg/L, 1000mg/L, 1500mg/L, 2000mg/L. The coagulation mixing conditions of the single factor experiment were determined by empirical method, the fast mixing speed is 300 rpm, fast mixing time is 90s, slow stirring speed of 50 rpm, slow mixing time is 5min, settling time is 30min.

Once the flocculant dosage was determined, the optimal conditions of hydraulic mixing would be selected by the orthogonal experiments. The mixing speed was divided into fast level and slow level, selected the four factors associated with coagulation conditions: fast mixing speed, fast mixing time, slow mixing speed, slow mixing time. According to the requirement of the control index of coagulation experiment, G value is $500 \sim 1000 \text{ s}^{-1}$ in the mixed phase, and the time is less than 2min; The average G value of flocculation stage is $20 \sim 70 \text{ s}^{-1}$, and the average GT value is between 1×10^4 and 1×10^5 .

Considering the beaker experimental parameters selection, each factor chose three levels (Table 1), then carried out the $L_9(3^4)$ orthogonal experiment. The turbidity of the supernatant was taken as the evaluation index which was called residual turbidity of effect of coagulating settlement after 30min, and then find out the primary and secondary relationship of each influencing factor, and chose the best combination of working conditions.

Table 1 Selection of parameters of orthogonal experiment at 20°C

Factor	Level number		
	1	2	3
Fast mixing speed (rpm)/G value	200/280	300/514	400/796
Fast mixing time (s)	30	60	90
Slow mixing speed(rpm)/G value	35/21	50/35	65/52
Slow mixing time(min)	5	10	15
Settling time(min)	30		

IV. EXPERIMENTAL RESULTS AND ANALYSIS

A. Single-factor contrast experiment of flocculant dosage

As shown in Table 2, when the dosage was 200mg/L and 500mg/L, the turbidity was large, the reason was that the flocculant dosage was too small, and there are still some

colloid and COD particles in water which were not broke and flocculated by flocculant; When the dosage was 2000mg/L, the turbidity was even higher than the dosage of 1500mg/L, that was because the excessive dosage resulted in the excessively balance of the potential of colloid particles, and that balance caused the stability of flocculation which was unable to continue the combination of large solid particles, and then there was a lot of small flocs in water, so the turbidity is higher compared with 1500mg/L. The above analysis combined with the experimental process, 1500mg/L was considered as the best dosage of the flocculant.

Table 2 single factor experimental results of flocculant dosage

dosage mg/L	0(raw water)	200	500	1000	1500	2000
Turbidity NTU	46.5	43	23	5.9	2.7	3.9

B. Orthogonal experiment of optimal mixing parameters

According to the type of (1)-(3), the horizontal effect values K_{mn} 、 \bar{K}_{mn} of each column and range value R were calculated. By comparing the magnitude of the range value R, the primary and secondary relationships among these factors were determined. By comparing the satisfactory values of indicators of horizontal effect values \bar{K}_{mn} from a same factor, the reasonable working conditions were determined.

$$K_{mn} = \text{sum of } n \text{ horizontal index in } m \text{ column} \quad (1)$$

$$\bar{K}_{mn} = \frac{K_{mn}}{\text{horizontal repeat frequency of } n \text{ in } m \text{ column}} \quad (2)$$

$$R_m = \text{the maximum value of } \bar{K}_{mn} \text{ in } m \text{ column} - \text{the minimum values of } \bar{K}_{mn} \text{ in } m \text{ column} \quad (3)$$

The value of the range R shows that the effects degree of experimental conditions on coagulation mixing: the mixing time > the fast stirring time > the fast stirring speed > the slow stirring time > the slow stirring speed. According to the horizontal effect values \bar{K}_{mn} in Table 3, and considering the speed and time, the optimal combination of the factors is obtained: the fast mixing speed is 400rpm, the fast mixing time is 90s, the slow mixing speed is 65rpm, the slow mixing time is 10min.

The effects degree of experimental conditions and the optimal combination of the factors show that the adequate time of fast mixing is the precondition for the flocculant to be well-distributed and guarantee for the flocculation effect, that's in agreement with the theory that coagulation is combined with condensation and flocculation; And fast mixing speed determines the turbulence phase condensation degree in condensation process, therefore, it also plays an important role in the coagulation effect.

Table 3 orthogonal experiment table $L_9(3^4)$ and results

Ordinal	A	B	C	D	Residual turbidity (NTU)
1	1	1	1	1	46.5
2	2	1	1	2	43
3	3	1	1	3	23
4	1	2	1	1	5.9
5	2	2	1	2	2.7
6	3	2	1	3	3.9
7	1	3	1	1	5.9
8	2	3	1	2	2.7
9	3	3	1	3	3.9

1	200	30	35	5	13
2	200	60	50	10	4.8
3	200	90	65	15	3.7
4	300	30	50	15	5.8
5	300	60	65	5	4.7
6	300	90	35	10	3.8
7	400	30	65	10	4.2
8	400	60	35	15	2.7
9	400	90	50	5	3.6
K ₁	21.5	23	19.5	21.3	comments
K ₂	14.3	14.4	14.2	12.8	
K ₃	10.5	11.5	12.6	13.7	
\bar{K}_1	7.2	7.7	6.5	7.1	
\bar{K}_2	4.8	4.8	4.7	4.3	
\bar{K}_3	3.5*	3.8*	4.2*	4.6*	
R	3.7	3.9	2.3	2.5	

Through the comparison of the horizontal effect value, it is found that in the slow mixing stage, the mixing time is not the longer the better, and long mixing time leads to the decline of the precipitation performance, that's because long time mixing will cause the shear fatigue appear at the connection between the aggregates and lead to the final fracture, the form is that the body is broken into small slags which cannot be precipitated, thus, the turbidity is increased. Therefore, whether it is the experiment or engineering practice, mixing time should not be too long.

V. CONCLUSION

In this paper, the basic principle of coagulation dynamics was divided into two parts, the coagulation mechanism and the mixing mechanism, and both mechanisms were generally described. Then two main experiments were designed. The optimal dosage of flocculant (PAC) was determined by single-factor experiment, and the dosage was 1500mg/L. Through the orthogonal experiments, the optimum condition of coagulation mixing were found: fast mixing rotational speed is 400rpm, fast mixing time is 90s, slow rotational speed is 65rpm, slow mixing time is 10min; And the effects degree of experimental conditions on coagulation mixing were found: fast mixing time > fast mixing speed > slow mixing time > slow mixing speed. This study provides theoretical support for the application of coagulation mixing in water treatment.

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